DREDGED MATERIAL RESEARCH PROGRAM

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LAND APPLICATION OF WASTE MATERIALS FROM DREDGING, CONSTRUCTION, AND DEMOLITION PROCESSES

by

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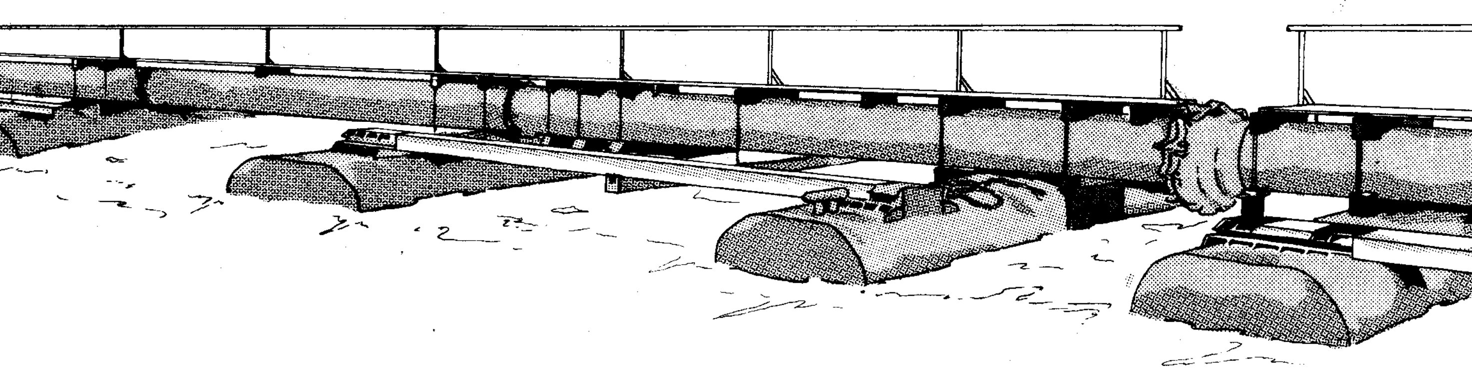

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This paper presents the text of a manuscript to be published as a chapter in a monograph of the symposium entitled "Land Application of Waste Materials," sponsored by the Soil Conservation Society of America. The paper is divided into two sections: waste materials generated by the dredging process and by the construction and demolition processes. Quantities and the general physical and chemical characteristics of the waste materials for each process are
(Continued)

20. ABSTRACT (Continued)

described. The potential use of these materials for land application for agricultural production is discussed as well as other potential uses such as land improvement, wildlife habitat development, recreational facilities, and industrial and residential landfill. The environmental impact of using these materials is described with emphasis on the legal restrictions as well as the social and psychological concerns to be considered. Certain dredged material will no doubt be beneficial to specific land application sites. However, all dredged material will not be suitable for land application. The dilemma to be reconciled is to determine which dredged material and application sites are environmentally compatible. Information is being generated through the Dredged Material Research Program, under the direction of the U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. This information coupled with sound scientific management should achieve productive uses of dredged material that are technically satisfactory, environmentally compatible, and economically feasible.

PREFACE

This paper was presented at the Soil Conservation Society of America Symposium on "Land Application of Waste Materials" held in Des Moines, Iowa, on 15-18 March 1976 and was prepared for publication in a monograph of the symposium proceedings by the Soil Conservation Society of America.

This paper is a review article for dredged material research funded by the Department of the Army under the Dredged Material Research Program, sponsored by the Office, Chief of Engineers.

This review of research was conducted at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, by Drs. C. R. Lee, R. M. Engler, and J. L. Mahloch of the Environmental Effects Laboratory (EEL). The paper was prepared under the general supervision of Dr. John Harrison, Chief, EEL.

Directors of WES during the preparation and publication of the paper were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
miles (U. S. statute)	1609.344	metres
cubic yards	0.7645549	cubic metres
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic yard	0.5932764	kilograms per cubic metre
tons (short, 2000 lb)	907.1847	kilograms
tons per acre	2241.7334	kilograms per hectare

LAND APPLICATION OF WASTE MATERIALS FROM DREDGING, CONSTRUCTION, AND DEMOLITION PROCESSES

Waste Materials from Dredging

Navigable waterways of the United States have through the years played a vital role in the Nation's economic growth. The Corps of Engineers (CE), in fulfilling its mission to maintain, improve, and extend these waterways, is responsible for the dredging and disposal of large volumes of sediment each year. Dredging is a process by which sediments are removed from the bottom of streams, rivers, lakes, and coastal waters; transported via ship, barge, or pipeline; and discharged on land or in water. Annual quantities of dredged material currently average about 300,000,000 cubic yards* (186,000,000 dry tons) in maintenance dredging operations and about 80,000,000 cubic yards (48,000,000 dry tons) in new work dredging operations with the total annual cost now exceeding $150,000,000 (1). This average annual maintenance dredging total and an indication of the geographical distribution of this work are shown in Figure 1. The quantities of dredged material disposed in open water and in confinements on land are also indicated.

In recent years, as sediments in many waterways and harbors have become contaminated, concern has developed that dredging and disposal of this material may adversely affect water quality or aquatic organisms. A number of localized studies have been made to investigate the environmental impact of specific disposal practices and to explore alternative disposal methods. However, these studies have not provided sufficient definitive information on the environmental impact of current disposal practices, nor have they fully investigated alternative disposal methods. As a result, the CE was authorized by Congress in the 1970 River and Harbor Act to initiate a comprehensive nationwide study to provide more definitive information on the environmental impact of dredging and dredged material disposal operations and to develop new or improved dredged material disposal practices. The U. S. Army Engineer Waterways Experiment Station was assigned the responsibility to develop and manage a comprehensive multidisciplinary five-year multimillion-dollar research

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is found on page 3.

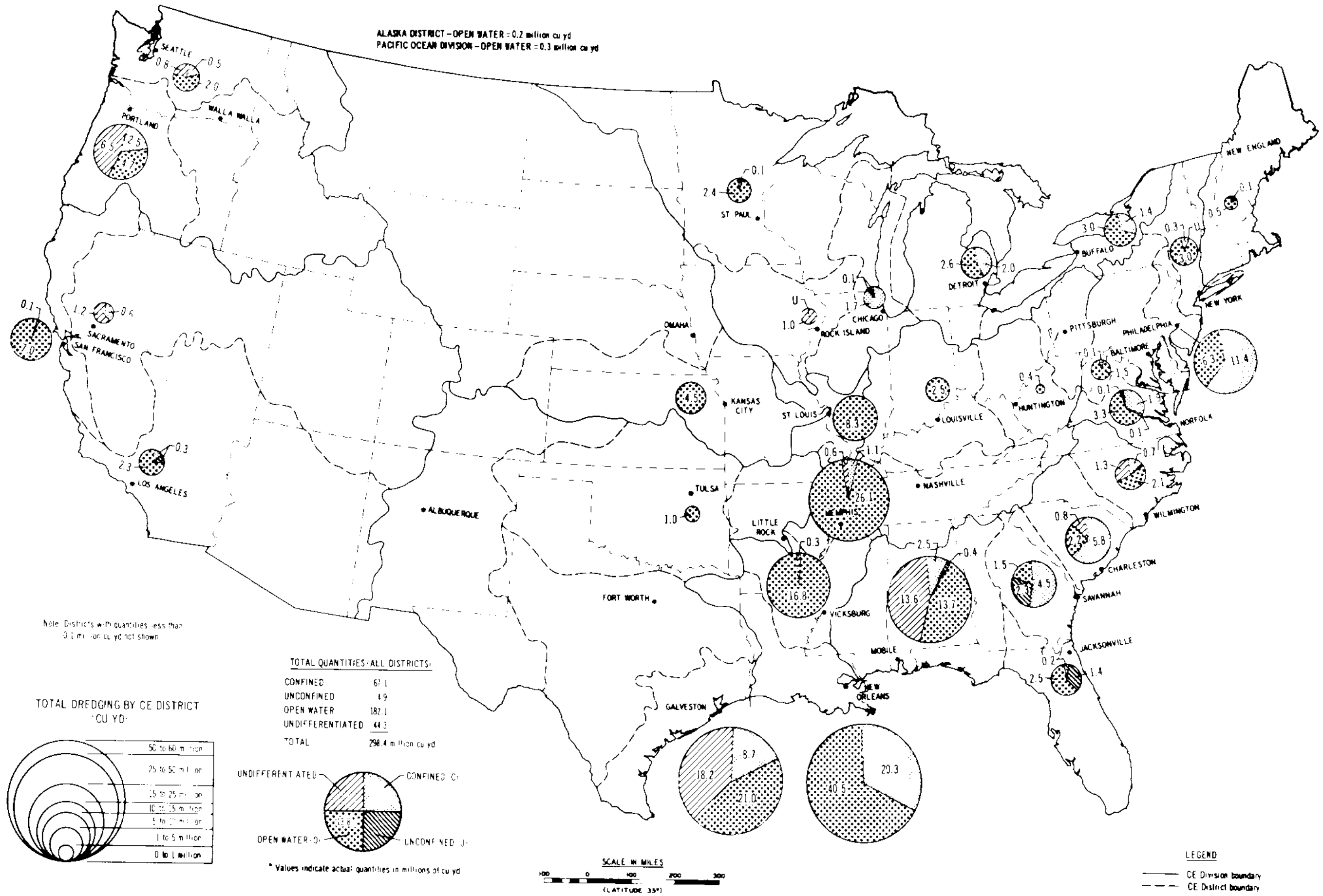


Figure 1. Disposition of dredged material generated in maintenance dredging operations and average annual quantities of material disposed of by area and by District (1).

program known as the Dredged Material Research Program (DMRP). Figure 2 illustrates the specific areas of research that will provide information related to land application of dredged material. A more detailed planning, technical, and management structure can be found in References 2 and 3. One of the major areas of research of the DMRP is to evaluate the productive uses of dredged material. Among the productive uses being examined is land application of dredged material for agricultural purposes. The DMRP will provide extensive and definitive information regarding the physical, chemical, and physicochemical characteristics of dredged material, the biological availability of the various components of dredged material, and the impact of disposal of dredged material on the environment. This information is currently being obtained and will be available in report form on or before 31 March 1978 at the conclusion of the DMRP.

Composition of dredged material

Each year the Nation's waterways, lakes, and harbors accumulate materials from a host of different sources. The composition of the sediment accumulated in the waterways and harbors depends to a large extent on the sources contributing materials into them. One of the major contributing sources is the runoff of materials from land surfaces after rainfall. Rainfall, when causing soil erosion, detaches soil particles from terrestrial sources, transports the soil particles and any materials that have sorbed to the soil particles, and delivers these into streams, rivers, and lakes. Industrialization and the increased density of population along navigable waterways have further altered the physical and chemical nature of many watersheds, resulting in the contamination of some river and harbor sediments. The major components of dredged material to be discussed in the following paragraphs are texture, organic materials, cation exchange capacity, nutrients, sulfur, heavy metals, and salt.

Selected physical and chemical characteristics of typical marine, estuarine, and freshwater sediments are shown in Tables 1 and 2. Of particular interest are the high nutrient and organic loadings of these bottom sediments. This is especially significant if one considers

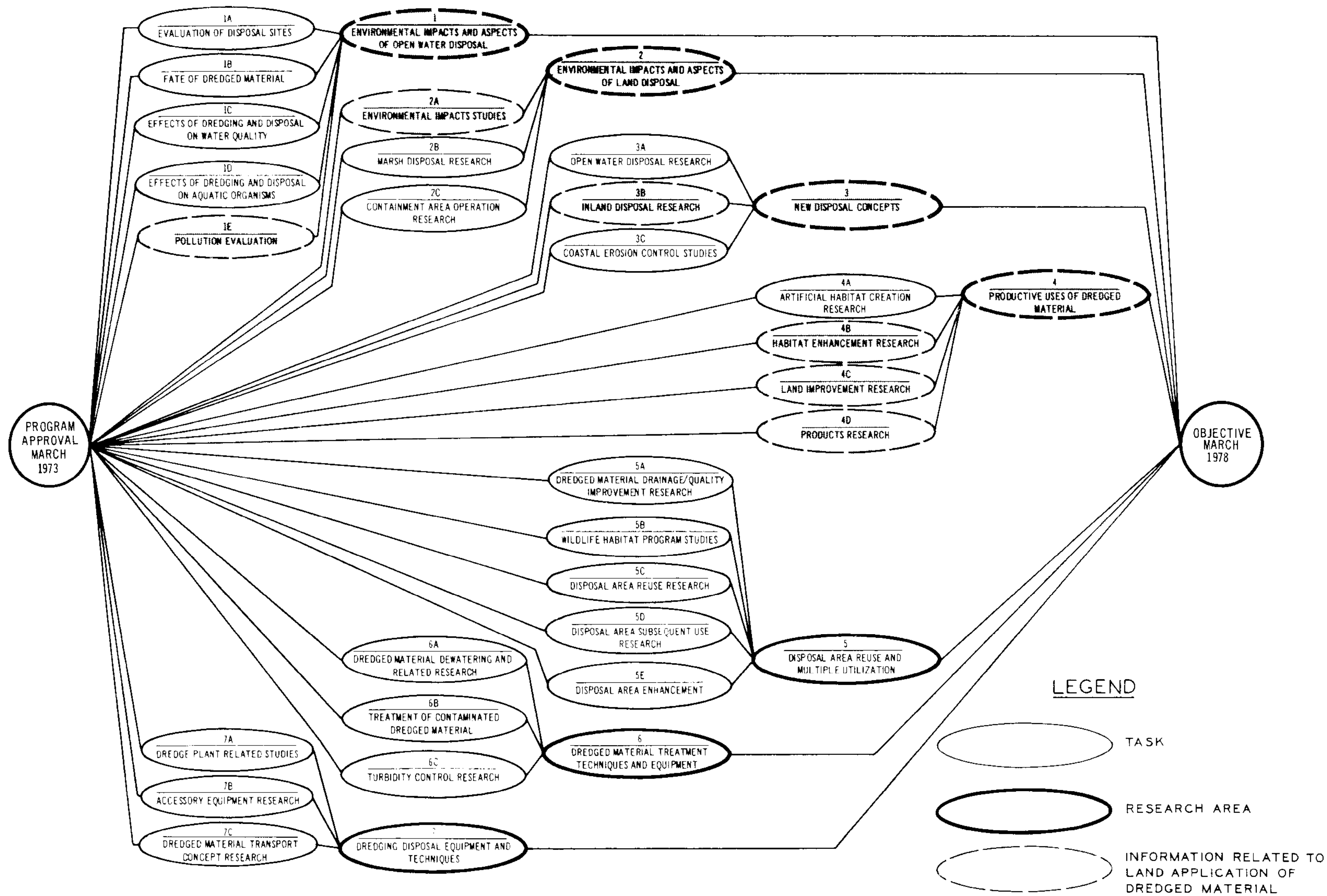


Figure 2. Dredged Material Research Program

Table 1

Average Physical and Chemical Characteristics of Sediments from Three Locations (4)

Parameter	Mobile Bay, Alabama	Ashtabula, Ohio	Bridgeport, Connecticut
	Location		
Particle size distribution, %			
<2 μm	52.7	36.0	38.3
2-50 μm	32.5	62.7	58.2
>50 μm	14.8	1.3	3.5
Cation exchange capacity, meq/100 g	46.3	16.9	23.9
Total organic carbon, %	2.03	2.42	2.69
Total inorganic carbon, %	0.07	0.56	2.19
Total sulfides, μg/g	903	240	2680
Total nitrogen, μg/g	1900	1390	2680
Total metals, μg/g			
Manganese	746	642	531
Nickel	156	213	203
Cadmium	3.62	4.14	17.60
Zinc	243	444	1067
Arsenic	4.08	6.50	6.90

Table 2

Characteristics of Sediments from Sampling Stations in Los Angeles Harbor (5) (in ppm - unless specified)

Parameters	Silty Sand Sta 1	Sandy Silt Sta 2	Silty Sand Sta 3	Silty Sand Sta 4	Silty Sand Sta 5	Silty Clay Sta 6
Total organic carbon, %	1.09	1.90	2.00	0.84	1.11	2.12
Chemical oxygen demand	--	52,590	29,210	21,450	22,870	116,800
Immediate oxygen demand	--	538	383	350	181	1,570
Total volatile solids, %	--	4.6	2.8	2.0	2.1	10.1
Sulfide	--	258	163	102	269	1,670
Organic nitrogen	--	357	689	588	459	2,820
Total nitrogen	--	357	706	636	493	2,920
Total phosphorus	--	886	679	644	787	1,470
Silver	4.5	16.9	7.1	3.5	5.4	10.2
Cadmium	2.42	1.90	0.66	0.66	2.45	2.20
Chromium	89	175	94	67	77	178
Copper	45	119	51	35	48	568
Iron	31,610	40,830	28,980	28,560	33,520	45,180
Mercury	--	0.68	0.28	0.27	0.38	1.43
Manganese	502	429	422	381	487	493
Nickel	22	35	23	18	22	47
Lead	39	67	47	32	36	332
Zinc	115	205	106	94	112	612

the variation in the physical characterization of the sediments.

Dredged material is composed predominantly of soil particles ranging in size from the coarsest sand to the finest clay and, depending on geographical location, can have an extremely mixed mineralogy. Individual dredged material deposits can vary from a well-ordered sand to a pure montmorillonitic clay. The nationwide distribution of dredged material by grain size is shown in Figure 3. In addition to soil, dredged material can contain other solids such as rock, wood, pieces of metal, broken glass, and other debris. Anthropogenic influences are evident as contamination of these sediments in the form of sewage materials, elevated concentrations of heavy metals, and a vast array of chlorinated hydrocarbons, oils and grease, and other organics. There is no standard method used to identify and classify dredged material (1). However, the terms used to identify dredged material range from basic terminology of gravel, sand, silt, clay, or combinations thereof to less descriptive terms such as sludge, mud, topsoil, and muck. The basic terminology is derived from the Unified Soil Classification System.

Dredged material can vary widely in organic matter content from very little to organically rich. More than half of the material dredged in the New England Division and Chicago District of the CE has a high organic content (Figure 3). All CE Districts have reported the presence of organic materials in maintenance dredging but in most cases not in large enough quantities to be shown in Figure 3. Organic carbon concentrations in dredged material as high as 10 percent are not uncommon but comprise only a small volume of the materials dredged. Also included in the organic fraction of dredged material could be petroleum products, persistent organics, pesticides, and herbicides. The concentrations of petroleum products will depend primarily on the extent of industrialization and the amount of traffic along the waterway. Contents of oil and grease in dredged material have been reported to range from less than 1 part per million to as much as 11,700 parts per million and consist of combinations of indigenous and man-induced forms (6).

The texture and organic matter content of a soil-sediment determine to a large extent the capacity of that material to sorb and desorb

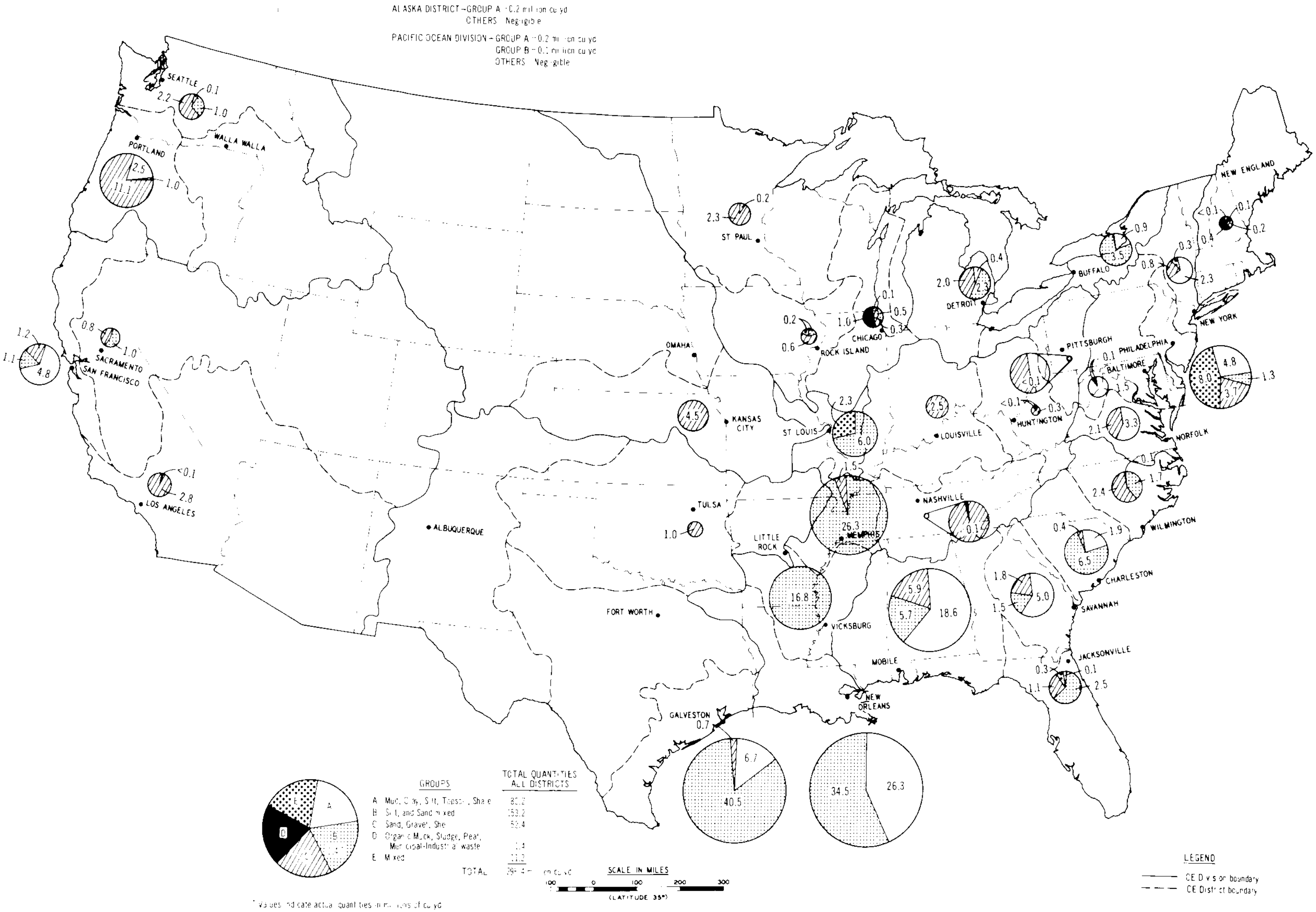


Figure 3. Grain-size classification of dredged material generated in maintenance dredging operations and average annual quantities of dredged material by type and by District (1).

cations, anions, oil and grease, and pesticides. Fine silt and clay textures along with relatively high contents of organic matter will enable a dredged material to sorb and fix a large amount of plant nutrients as well as many other constituents. The cation exchange capacity (CEC) of a dredged material governs the amounts of ammonium nitrogen, potassium, and other cations, heavy metals, and some pesticides that are sorbed in a dredged material. Toth and Ott (7) found the values of CEC in sediments from six major waterways along the East Coast to range from 7 to 100 milliequivalents per 100 grams. The higher CEC values were associated with organic matter contents ranging from 13 to 24 percent. Brannon et al. (4) found CEC values in sediment from Mobile Bay, Alabama, to range from 41 to 58 milliequivalents per 100 grams. The potential of these materials as an amendment to marginal soils is apparent.

The nutrient content of dredged material can be expected to vary widely, as does that of different soils. Generally, the finer textured dredged material contains considerably more nutrients than coarse-textured dredged material. Total nitrogen contents of some dredged material have been reported to range from 0.02 to 0.37 percent and vary widely with geographic location (4,5,6,8,9). The most predominant form of nitrogen in inorganic sediments is ammonium nitrogen; however, in organically enriched sediment, organic nitrogen predominantes, even though ammonium concentrations can be very high.

In most sediments as in soils, phosphorus occurs as a phosphorus-solid complex (10). Total phosphorus contents of sediments and dredged materials have been reported to range from 450 to 3600 parts per million (8,9). Soluble phosphorus in these materials, however, was only 0.8 to 8.8 parts per million. Recent studies conducted by Brannon et al. (4) and Chen et al. (5) have shown similar total phosphorus concentrations in marine, estuarine, and freshwater sediments. However, interstitial water orthophosphate concentrations have been found as high as 80 ppm in these recent anaerobic sediments. Care was taken prior to and during the analytical procedures to preserve the anaerobic integrity of these sediment samples.

Exchangeable amounts of potassium have been found to vary from 150 to 1050 parts per million in sediments along the East Coast (7) and in the Lower Great Lakes Region (9). Dredged material will also contain varying amounts of soluble, exchangeable, and total calcium and magnesium.

Dredged material can be expected to contain wide ranges of sulfur. Concentrations of total sulfide in anaerobic dredged material have been shown to range from zero to 5390 parts per million in mineral sediments from marine, estuarine, and freshwater sediments (4,5). Free sulfides were noted in some samples at concentrations of 200 parts per million. Fleming and Alexander (11) reported that sediments in a South Carolina tidal marsh developed high acidity when drained and allowed to dry out. These sediments contained up to 5.5 percent total sulfur; when drained, sulfides were oxidized to sulfate with a resultant decrease in sediment pH from 6.4 to as low as 2.0. Similar sulfur acidity problems have been described for soils known as Katteklei (cat's clay) in Holland (12) and other locations along the East Coast of the United States (13). In dredged material containing high levels (usually greater than 0.1 percent) of nonvolatile sulfide, predominantly iron and manganese sulfide, "cat's clay" effects may be a serious problem. This is especially true if the dredged material is not limed or counteracted by application to an alkaline upland soil.

A number of sediments from rivers, harbors, and bays throughout this Nation and in Canada have been reported to contain a wide range of concentrations of heavy metals (4,5,8,9,14,15,16). Some of the major sources of heavy metals that contribute to abnormally elevated metal concentrations in dredged material are industry discharges, sewage discharges, urban and highway runoff waters, and snow removal. Wastes from the metal plating industries which have found their way into some sediments contain significant amounts of copper, chromium, zinc, nickel, and cadmium (17). Large concentrations of lead were found in the sediment of the Rideau River in Ottawa, Canada, at the river dumping site of snow removal operations (15). Sediment chemical partitioning studies (4,5) have shown these contaminant metals to occupy the least stable of the sediment fractions and that the sediment physicochemistry dominates the mobility and availability of the contaminant as well as the indigenous metals.

The quantities of heavy metals discharged from industries that process or utilize heavy metals and from municipal sewage depend on the degree of pretreatment of discharged wastewaters. These quantities have been relatively large in the past, but recent clean-water legislation (PL 92-500, Federal Water Pollution Control Act Amendments of 1972; and PL 92-532, Marine Protection, Research and Sanctuaries Act of 1972) will require more complete pretreatment of wastewaters and should result in a substantial reduction in the heavy metal and other contaminant contents of discharged wastewaters in the future.

The potential for a heavy metal to become a contaminant depends greatly on its form and availability rather than its total concentration within a sediment. Characterization of the mobility and availability of heavy metals in dredged material is one of the objectives of the DMRP through continuing research by Brannon et al. (4), Chen et al. (5) and Lee et al. (6). Considerable information is being generated and should be forthcoming at the conclusion of the DMRP.

The last major component of dredged material to consider is salt. Dredging in coastal waters especially results in dredged material containing various amounts of salt and in some cases as much as 3 percent (18). Chloride content of inland harbor sediments can also be elevated from various wastewater inputs. The salt content of dredged material would have to be reduced before land application should be considered or similar salinity problems as described by Stewart (19) may result.

Methods of collection and transport

Sediments are removed from waterways and are conveyed to disposal areas either hydraulically or mechanically (20). Hydraulic handling of dredged material is by far the more common method (Figure 4) and is used to excavate and transport about 96 percent of the volume of material dredged each year. It is accomplished by suction excavation and pumping through submerged or floating pipeline from a pipeline dredge, through

Figure 4. Hydraulic pipeline conveying dredged material to disposal site

direct pumpout from a hopper dredge (ship capable of ocean navigation) moored at the disposal site, or by a combination of the two methods through the use of a rehandling basin that receives dredged material from the hopper dredge or from scows which is then pumped out into the permanent disposal area, such as at Craney Island, Norfolk, Virginia (20).

Mechanical handling of dredged material is accomplished with dipper dredges, bucket dredges (especially draglines), and ladder dredges (20). These mechanical methods are used especially in congested harbor areas for very small dredging projects, dredging of oversized debris, and for secondary tasks such as dike building and clearing out rehandling basins on major projects.

Two methods can be employed for land application of dredged material. Disposal of dredged material can be accomplished via a pipeline directly onto land sites in reasonable proximity of the dredging operations (Figure 4). Disposal in this manner results in the application of a slurry containing from 12 to 20 percent solids. Potential problems with this method of land application of dredged material would be similar to the application of other solid waste slurries upon land, namely runoff water quality and effects on groundwater quality.

An alternate and perhaps more practical method for the application of dredged material to land would involve the use of predried or semidried and somewhat consolidated dredged material obtained from permanent dredged material containment facilities. In this way, dredged material would be deposited into a containment area, where it segregates into various particle-size distributions, consolidates somewhat, and begins to dry out. The dredged material can then be reworked, loaded into dump trucks or other suitable vehicles via a dragline or front-end loader, and transported to the land application site. This method would allow dredged material removed from brackish and saltwater environments to be leached by rainfall to remove excess salt before removal from the containment area for application to land as well as allow selection of specific textures and densities desired for a specific land application site. However, this method also allows natural invasion of weeds into a disposal site, which may reduce the value of the dredged material for agricultural use.

Potential for the land application of dredged material

The potential of applying dredged material to land is determined by the planned use of the application site. Alternative uses of land application sites of dredged material are listed in Table 3. In the following paragraphs, a number of successful uses of application sites will be cited where possible, as well as future potential uses of land receiving dredged material applications.

Certain dredged material will no doubt be beneficial for agricultural production on specific land application sites. However, all dredged material will not be suitable for land application. The dilemma to be reconciled is to determine which dredged material and application sites are environmentally compatible.

The benefits of land application of dredged material are in some respects similar to the benefits of waste disposal on land described by Larson et al. (21). Larson et al. (21) emphasized an essential component of land application of waste that should be reemphasized here. That is, soil improvements due to the application of wastes do not come automatically. Sound scientific management of waste material applications to the land is necessary to minimize the undesirable consequences that could result.

The major features of dredged material that must be considered in land application for agricultural purposes are its water content, texture, organic loading, cation exchange capacity, nutrient content, sulfide-sulfur content, essential or toxic heavy metal content, salt concentration, and weed content.

There appear to be two major potential uses for dredged material according to texture. One use is for sandy coarse-grained materials; the other is for fine clay and silty clay textured materials. Sandy dredged material is generally low in organic material content, cation exchange capacity, and available nutrient and heavy metal concentrations. Dredged material of this type may have potential as an amendment to heavy impermeable clay soils in order to improve structure and

Table 3

Alternate Uses of Land Application of Dredged Material

1. Agricultural production (food and fiber crop production).
2. Land improvement (reclamation of disturbed areas and raising elevation of lowlands).
3. Wildlife habitat development (marsh, island, and upland habitat creation).
4. Recreational facilities (park creation, enhancement of golf courses).
5. Industrial and residential landfill.

permeability so as to enhance crop production of these soils. Another use of sandy dredged material could be in raising the elevation of lowlands used for agriculture. An example of the latter has been reported (20) where a farmer in Virginia increased the productivity and potential value of his agricultural land by excavating, removing, and stockpiling the topsoil and allowing the Norfolk District of the CE to dispose of sandy dredged material in the excavation site. The farmer then replaced the topsoil to continue farming at a higher elevation.

Finer textured dredged material represents the second major potential as an agricultural soil amendment on marginal or nutrient-deficient soils with poor moisture-holding capacity. Dredged material of a silt and clay texture is generally high in organic matter content, cation exchange capacity, available nutrients, and in some cases heavy metal loadings. These nutrient-rich materials could have potential in improving the agricultural productivity of marginally productive or unproductive alluvial soils located along waterways. These poorer agricultural soils may be sandy and/or silty in texture and would probably benefit from the addition of a nutrient-rich material with sufficient organic loadings to enhance the structure and moisture-holding capacity of the amended soil.

There have been a limited number of studies to evaluate the agricultural potential of fine-textured dredged material (22,23,24). In one study (22), various laboratory, greenhouse, and field experiments were conducted to determine the impact of adding a river sediment to both sandy and loamy textured soils. The sediment was of a silty clay texture with a cation exchange capacity of 28.5 milliequivalents per 100 grams, contained 9.4 percent organic matter, 0.4 percent nitrogen, and had a pH of 4.0. The air-dried sediment was limed to pH 6.5 and applied to soil at rates of 0 to 300 tons per acre. The addition of limed sediment to sandy soil increased the moisture-holding capacity, substantially increased the retention of applied nutrients, and increased the yield of various agronomic crops. This enhancement of the productivity of coarse-textured soils by sediment amendments was directly related to the silty clay and organic matter contents of the sediment.

There was no improvement in productivity when the limed sediment was added to the loamy soils. However, it was also noted that crops grown on the river sediment contained slightly more zinc and manganese than crops grown on soils not receiving dredged material additions. These elevated plant contents of heavy metals did not have any apparent adverse effects on crop growth or yield. It was therefore concluded that it is feasible for agricultural purposes to incorporate similar river sediments into either coarse- and fine-textured soils.

Two recent greenhouse studies, conducted in Canada (23,24), evaluated the production and heavy metal uptake of corn, tomato, ryegrass, and lettuce grown in sediments from various locations in the Great Lakes. These sediments were contaminated with heavy metals (Table 4). Some of the sediments were suitable for the growth of corn, tomatoes, and ryegrass. Lettuce, however, grew poorly in all sediments. It was concluded that the uptake of elements, including toxic ones, was mainly dependent on the specific plant species and less on the character or total contaminant concentration of the sediment (Table 4). The majority of trace elements were taken up and accumulated in the plant roots and transferred to other plant parts in small amounts such that the concentrations in leaves and fruits were considerably less than toxic levels.

Research is being conducted in the Netherlands by Dr. A. J. deGroot in association with the Adriaan Volker Dredging Company (25) to assess the growth and heavy metal absorption of agronomic crops grown on the contaminated sediment from the Rhine River. These studies currently report relationships of the cadmium content of plant parts of selected crops with the total cadmium content of the dredged material (Figure 5). The pH of the dredged material ranged from 7.0 to 8.0. Other heavy metals being studied are lead, nickel, chromium, iron, zinc, copper, and manganese.

These studies emphasize the importance in characterization of a dredged material with respect to organic matter content, cation exchange capacity, nutrient levels, sulfur, and heavy metal concentrations. Organic matter will improve the moisture- and nutrient-holding capacity

Table 4

Concentration of Elements (ppm) in Two Great Lake Bottom Sediments and in Ryegrass and Lettuce Plants Grown in the Sediments (24)

	Location					
	Hamilton Harbour			Lake St. Clair		
Element	Sediment	Ryegrass	Lettuce	Sediment	Ryegrass	Lettuce
Copper	114	4-31	11-21	25	2-18	11-19
Zinc	4,800	200-700	110-297	59	40-97	80-145
Lead	580	4-14	<1	24	6-12	<1-10
Cobalt	20	<1-4	1-4	10	<1-4	<1-2
Nickel	50	<2-10	6-9	20	6-10	3-5
Molybdenum	10	<2-8	<2	<2	<2-6	<2
Cadmium	11	<1-1	2-5	4	<1-1	1-4
Chromium	165	<1-15	1-5	17	<1-3	1-4
Strontium	40	25-37	29-40	55	10-30	10-20
Manganese	2,350	110-1,200	650-1,000	300	46-100	58-74
Iron	138,500	<50-1,640	160-270	18,750	50-275	155-225
Mercury, ppb	600	<20-500	<20-60	3,860	<20-110	760-1,000

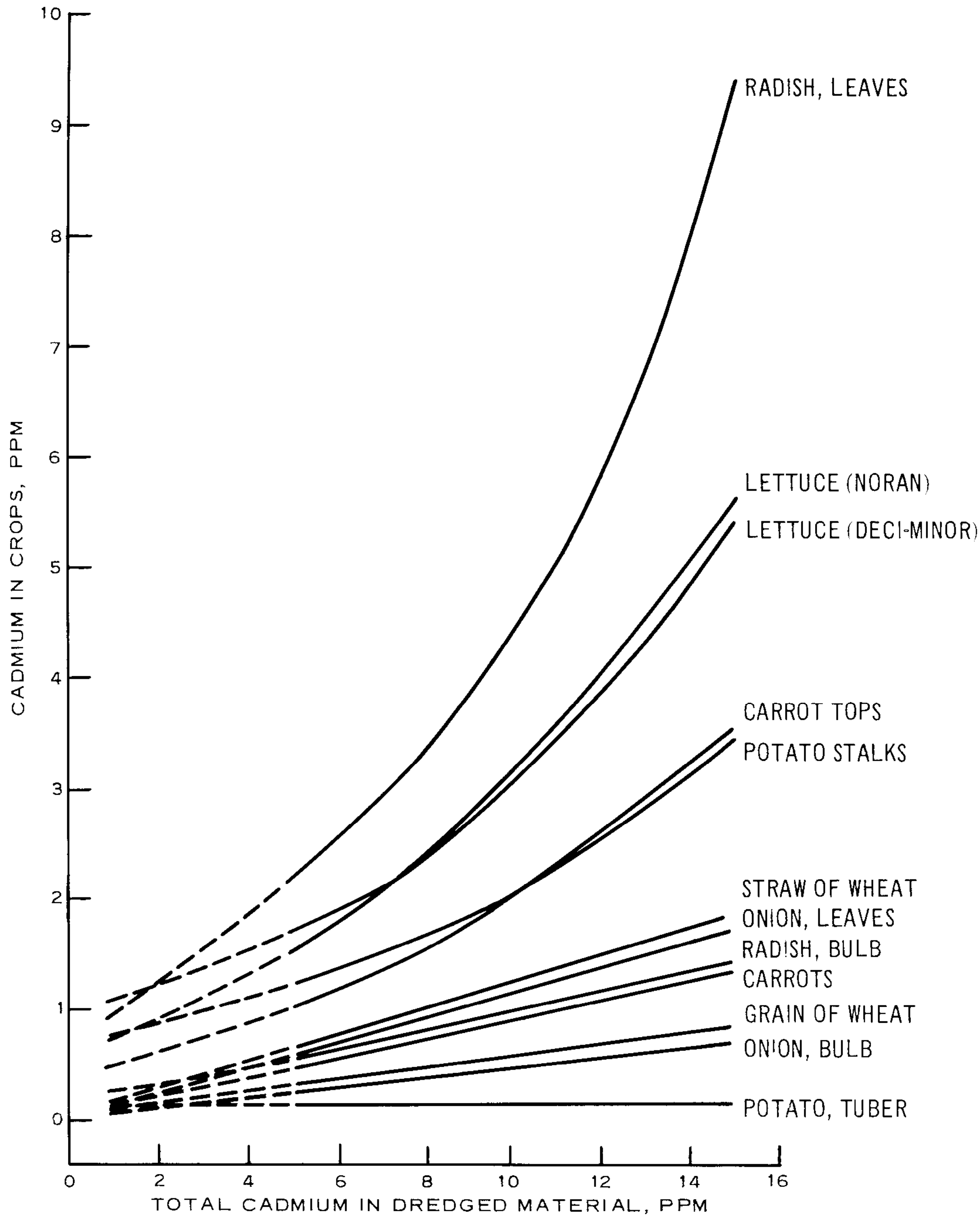


Figure 5. Relationship between the amount of total cadmium in dredged material and the amount of cadmium in the crops cultivated on it (25).

of coarser droughty soils and can also enhance the structure and permeability or porosity of poorly drained heavy clay soils. The sulfide-sulfur content, mineralogy, and texture of dredged material should indicate the potential effect on soil pH that aeration and subsequent oxidation of an anaerobic dredged material will have when applied to land.

Nitrogen applied to land in dredged material will undergo the transformations that normally occur under oxidized or aerobic conditions. Ammonia volatilization, mineralization, nitrification, and denitrification can occur. The rate of these transformations will vary with soil characteristics and the concentration and forms of nitrogen in the dredged material. While there is no information available on nitrogen transformation in dredged material applied to land, some insight can be gained from the information published on sewage sludges (26), farm manures (27), and marsh and swamp soils (28).

Losses of nitrogen from dredged material by ammonia volatilization would probably approach that found with sewage sludge (26) and farm manure (27) under similar application conditions. Ryan and Keeney (26) applied sewage sludge to the surface of the soil under laboratory conditions and found that from 11 to 60 percent of the ammonium nitrogen was lost by volatilization. Salter and Schollenberger (27) applied farm manure to the soil surface and found that about one-half of the ammonium nitrogen was lost as ammonia in the first three or four days. Incorporation of dredged material into the soil and maintaining a slightly acid soil pH will reduce losses from ammonia volatilization.

Mineralization of organic nitrogen in dredged material would probably approach that found with animal manure. Peterson et al. (29) suggested that the mineralization rate of nitrogen from animal manure during the first year after application averaged 50 percent.

Ammonium nitrogen will rapidly undergo nitrification to nitrate in an aerobic soil and be available for plant uptake or loss by leaching. Depending on soil moisture, denitrification may also occur to convert nitrate nitrogen to gaseous nitrogen with concomitant significant losses in nitrogen (30).

Phosphorus, potassium, calcium, and magnesium contained in dredged material are normally high and should be available for plant growth through normal exchange reactions.

Heavy metals may be fixed in a slightly soluble form in sediments containing sulfide. However, land application of the dredged sediment, if allowed to dry out and oxidize, may increase the solubility of heavy metal sulfides by oxidation of the metal sulfides and a decrease in pH to more acidic levels where the metals may exist as ions or sulfates, oxides, hydroxides, and chlorides. Under oxidized conditions, the solubility and availability of the heavy metals no longer are governed by sulfur but rather by soil pH and heavy metal hydroxyl and oxide formation. A recent article by Engler and Patrick (31) describes the stability and plant availability of various heavy metal sulfides in anaerobic and aerobic soil systems. Organic matter will be effective in chelating heavy metals whether the sediment is at the bottom of a waterway or dredged and applied to land. Heavy metals applied to land in dredged material will probably remain near the area of application or the surface of the soil sorbed and chelated in the organic matter. Agricultural crops may take up some of the heavy metals as Mudroch has reported (23,24). However, scientifically sound management practices should be employed so that excess amounts of available heavy metals are not applied to the land.

The quantity of nutrient-rich dredged material that can be applied to a soil will be determined by the nutrient content of the dredged material, the type and texture of soil, and the nutrient requirements of the crop to be grown. Nitrogen is the nutrient that is of major concern in the application of many waste materials to land (21). Excess amounts of nitrogen usually leach as nitrate into groundwater. A general rule of thumb for the rate of waste material application on land has been reported that twice as much nitrogen as that desired for crop production should be applied to the soil (21). Current feelings are that only the amount of nitrogen required for crop production should be applied as a waste material. There has been no research to verify if this applies equally well to dredged material.

Until further information is available, land application of dredged material containing significant amounts of either petroleum products, chlorinated hydrocarbons, sulfide-sulfur, or plant-available toxic heavy metals should be minimized. The DMRP will develop methodologies that will give some guidance for the selection of environmentally compatible dredged material for various land application practices.

A recent survey (32) of the attitudes of State officials revealed two additional beneficial uses of dredged material to be as a topping or cover over sanitary landfills and in reclaiming strip-mined areas. Addition of nutrient-rich dredged material may enhance plant growth and the general appearance of these areas. The ion-sorption capacity of fine-grained sediments may be beneficial in reducing leachate problems associated with sanitary landfill areas when layered with the sanitary waste material. The DMRP is currently obtaining information on the feasibility of these and other innovative potential uses of dredged material.

Other potential uses of dredged material are the creation and development of wildlife habitats. Certain types of dredged material lend themselves to the creation of marsh, island, and upland wildlife habitats. The DMRP is addressing the methodologies to be used in the creation of wildlife habitats in an environmentally acceptable manner.

The use of dredged material has recently been reported to be an economically efficient manner to create recreational land in urban areas (33). The existing need for recreational facilities, the increased quantities of leisure time, and the changing utilization of it suggest that the benefits from the recreational use of dredged material disposal sites can be substantial (33). Numerous examples of the successful use of dredged material for creation or protection of recreational facilities have been cited (33). Two such examples are Vacation Island in Mission Bay, San Diego, California (Figure 6), and Fort Massachusetts on Ship Island off the Mississippi Gulf Coast (Figure 7).

Dredged material is currently or has been proposed for use in the creation of a number of recreational parks (20,32,33,34). The Huron-Clinton Port Authority has proposed to develop parks at Point Moulet in

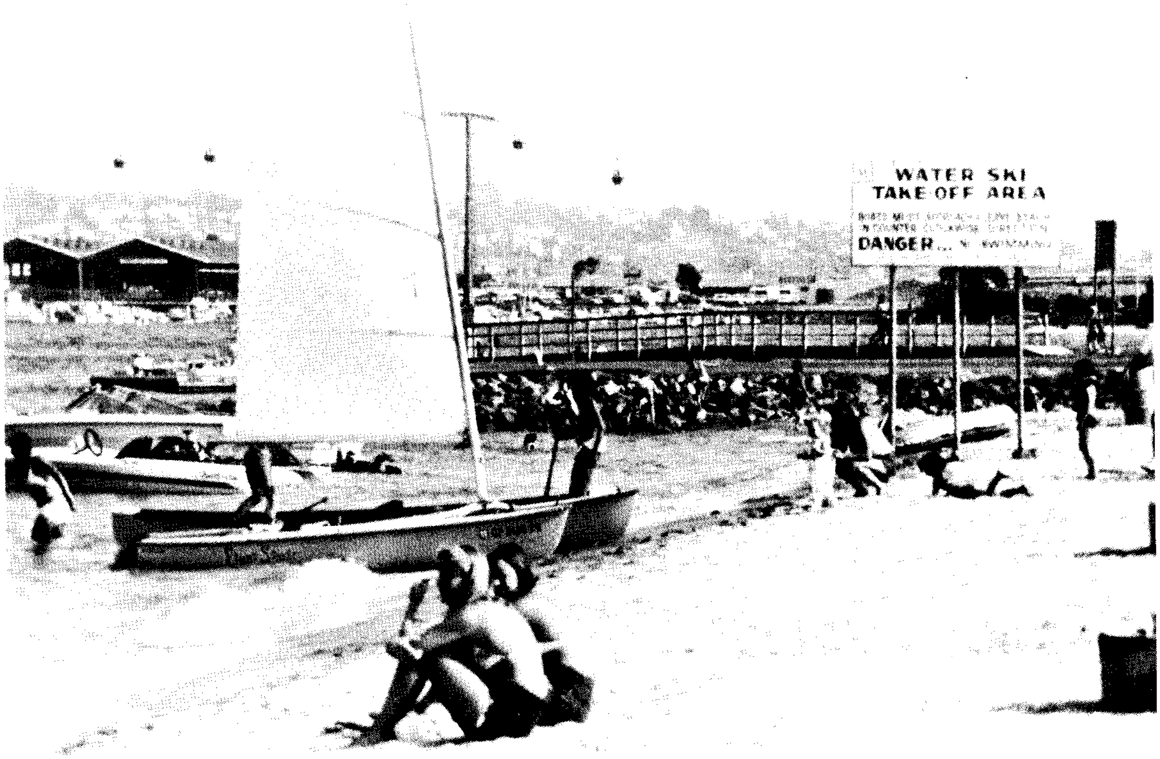
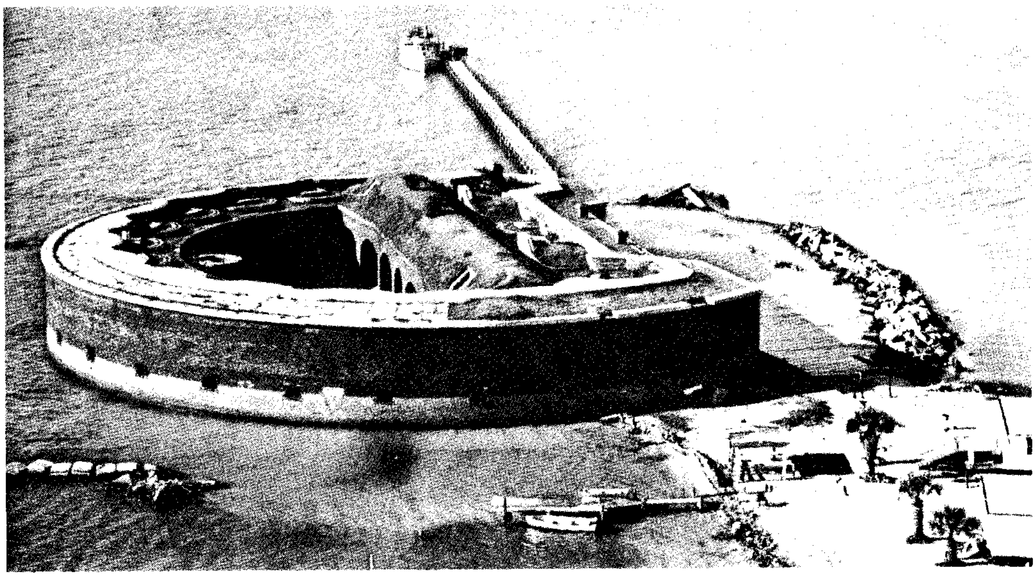
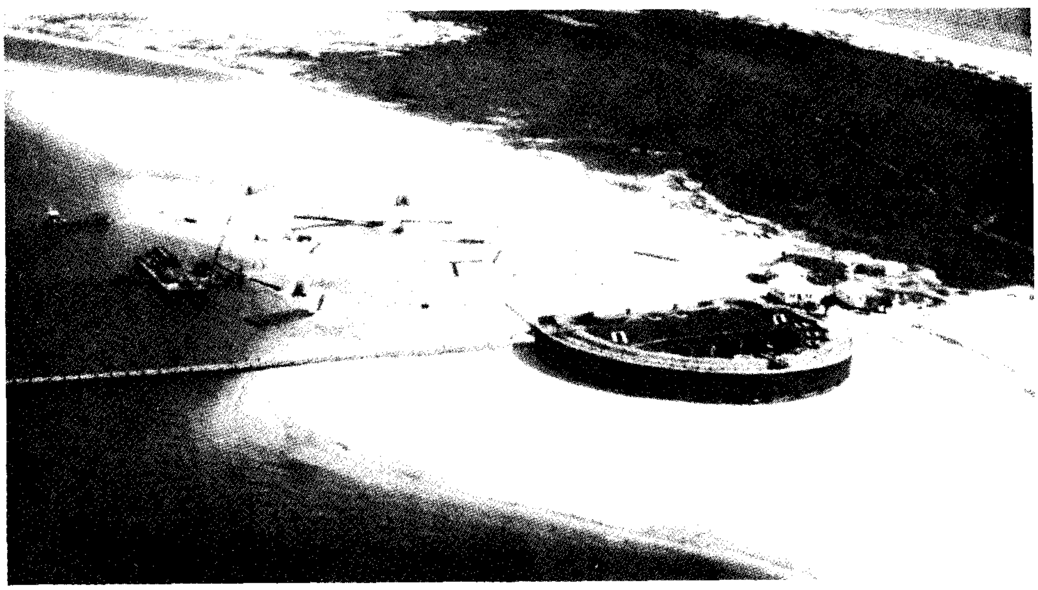


Figure 6. Vacation Island, created from dredged material in Mission Bay, San Diego, Los Angeles District (33).



Fort Massachusetts in 1973 prior to dredged material disposal



Fort Massachusetts in 1974 after dredged material disposal

Figure 7. Use of dredged material to isolate and protect Fort Massachusetts, a popular tourist attraction, from structurally damaging constant wave action (35)

the Detroit River and Dickinson Island in Lake St. Clair (20). These parks will provide fishing areas and boat launching ramps on the stone-protected embankments and picnicking and sports facilities within the area itself. The Galveston District of the CE in a design memorandum (34) cited recreational potential for the Sabine Lake dredged material disposal site in Port Arthur, Texas. Certain types of dredged material may have potential use in the construction, establishment, and enhancement of golf course fairways.

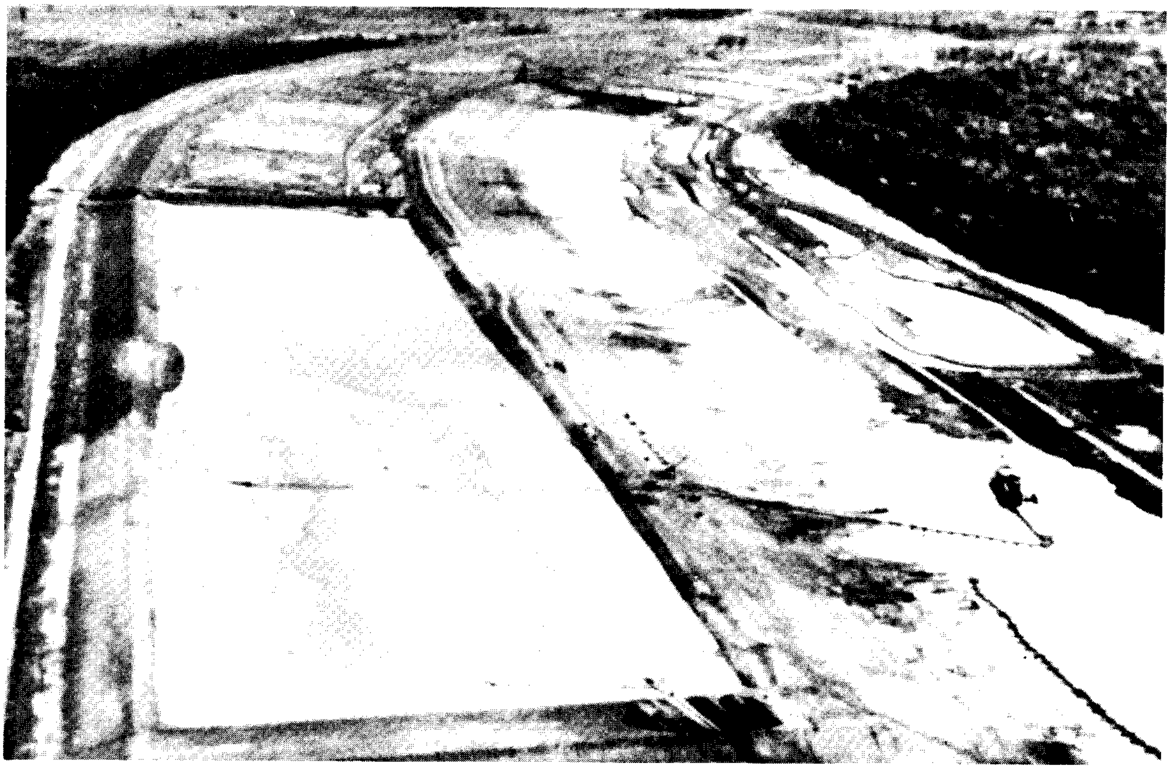
CE Districts have successfully used certain types of dredged material for industrial landfill. Along the Gulf Coast, coastal and lowland dredged material disposal sites have been used as sites for shipbuilding facilities, a coal handling plant, a bridge and iron works, seafood processing plants, ice plants, and heavy manufacturing industries (20). The Vicksburg District of the CE has used dredged material to create the Vicksburg Harbor industrial fill in order to provide an easily accessible industrial site above river flood stages to allow local trade interests to take advantage of cheap river transportation on the Mississippi (Figure 8). On the East Coast, examples of the use of sand and gravel dredged material fill sites can be cited in Philadelphia for food handling facilities and the Philadelphia airport (20).

These are only a few of the many successful landfill uses of dredged material.

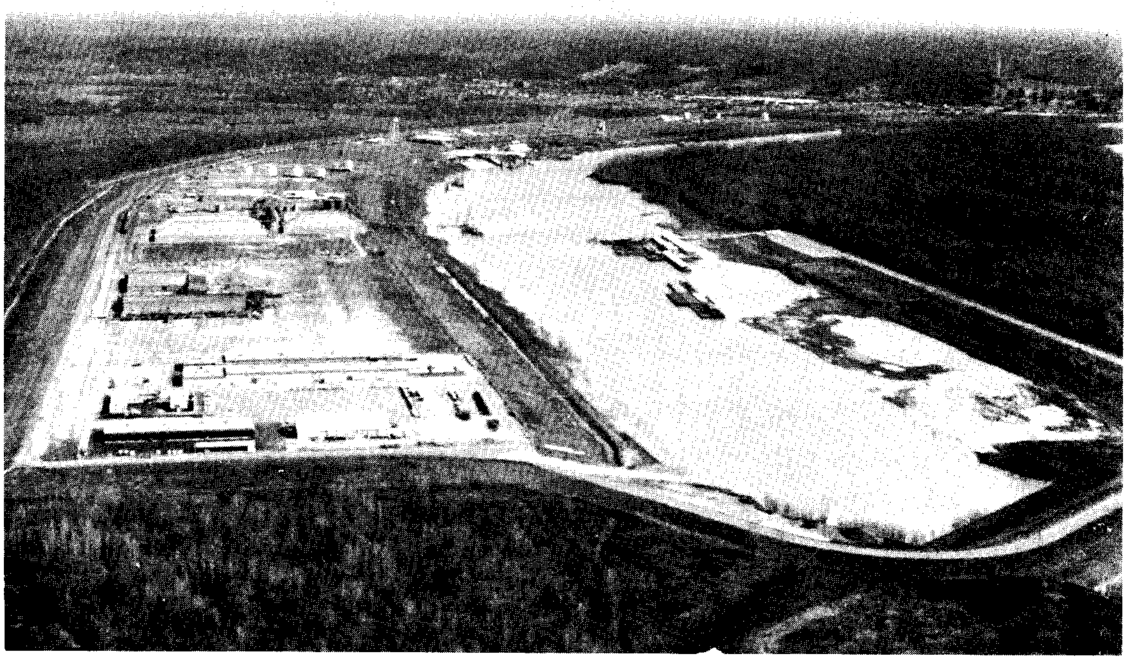
Legal land-application restrictions

Land application of dredged material will more than likely be subject to legal restraints imposed on land application of solid wastes, sludges, and wastewater (32,36). Accordingly, the impact of land application of dredged material on the environment, including public health, social, and economic aspects, should be addressed. Environmental assessments will more than likely be required for all federally funded projects, and similar reports and surveys will probably be required by many State and local governments.

Among the public health effects that should be assessed are groundwater quality, insects and rodents, runoff from application site, and chemical and biological contamination of crops. Groundwaters and



(a)



(b)

Figure 8. Use of dredged material to create the Vicksburg Harbor industrial site: (a) hydraulic filling in progress, (b) after occupation by several industries (20)

runoff waters should be monitored for the presence of leachable contaminants from the dredged material. Nitrates are the most common problem, but other constituents such as soluble organics, dissolved salts, trace elements, and human pathogens should be considered. Of all the Federal and State laws stating public policy, the water quality requirements are the most pervasive (32). They may in effect control what can be placed on land because of runoff problems and leachates reaching the groundwater. For these reasons, extensive preapplication characterization, monitoring, and control practices should be planned.

Since there is a possibility of contamination from pathogens in the dredged material, conventional control methods for insects and rodents on a land application site should be practiced. The effect of land application of dredged material on the contamination of crops grown on the site is of general concern. While there are no specific regulations regarding crop contamination from dredged material, many states have regulations dealing with the types of crops that may be grown with wastewater and the purpose for which the crops may be used. Similar regulations for growing crops on land receiving applications of dredged material may be forthcoming.

Social and psychological concerns

The overall effects of specific land applications of dredged material should be evaluated in light of their impact on the sociological aspects of the community (36). Public reaction has been reported to be opposed often to any use of nutrient-rich waste, dredged material, or sludge close to their living environment (32). The objections are usually based upon fear of foul odors, high concentration of metals and trace elements, and the persistence of some pathogenic organisms. Local nuisance ordinances may be enforced in the case of nutrient-rich material that is malodorous while moist. However, Larsen et al. (21) relate that odors from wastes can be minimized by thoroughly mixing and incorporating the materials into the soil.

Consideration should also be made of relocation of residents, effects of greenbelts and open space, effects on recreational activities, and effects on the quality of life (36). The requirement for large areas of land for application of dredged material may necessitate the purchase of land and possibly the relocation of residents. Land application of dredged material should be evaluated from an aesthetic point of view. Disruption of the local scenic character can be undesirable, while through proper design and planning, the beauty of the landscape can often be enhanced. Beneficial social effects can be obtained by reforestation and reclamation of disturbed areas such as those resulting from strip-mining operations. The creation or enhancement of recreational facilities should be considered. Land application of nutrient-rich dredged material to golf courses might enhance grass grown and therefore upgrade golf facilities.

Consideration should also be given to the economic impact of land application of dredged material. Factors that should be evaluated include (a) change in land values, (b) loss of tax revenues if governmental purchases are required, (c) conservation of resources and energy, and (d) change in quality of ground or surface waters.

Current research in the DMRP and elsewhere should generate much of the information necessary to enable the wise management of a reusable resource such as dredged material in an environmentally compatible manner.

Construction and Demolition Wastes

The transition of people and services out of the city to surrounding suburban areas has resulted in a general deterioration of downtown shopping areas in many cities. To alleviate parking problems in some cities, older buildings have been demolished and replaced with parking facilities (Figure 9). The need to improve housing for many middle and lower income families has increased urban renewal with the demolition of inadequate housing and the construction of more acceptable housing. These activities and others have given rise to problems of construction and demolition waste disposal. The following paragraphs will discuss some of the major factors regarding waste from construction and demolition processes and its disposal.

Figure 9. A recent newspaper photo showing the Seaboard Medical Building in downtown Miami, Florida, crumbling as 100 pounds of explosives are detonated during demolition (Courtesy of Wide World Photos, New York)

Composition of construction and demolition wastes

Wastes originating from the construction and demolition industry are composed of combustible and noncombustible materials generally oversized in nature. Primary components are concrete and masonry rubble, plaster, roofing, lumber, wiring, piping, and related products (37). In general, waste sources are primarily concentrated in the large urban areas where most of the industry activity is occurring. Waste volumes produced are subject to extreme variations depending on the influence of seasonal and economic factors.

Data related to volumes and compositions associated with construction wastes are generally missing due to a lack of specific inventories for this area. One study (37) reported the average production of noncombustibles from the construction industry to average 150 pounds per capita per year. These types of data must be regarded as speculative since actual amounts will vary due to the nature of construction and industrial activity. Typical waste volumes associated with new construction are presented in Table 5 (38). Included in construction waste would be any soil and bedrock, commonly referred to as "cellar dirt," produced during foundation establishment.

Wastes from the demolition industry have been inventoried recently (39), and there is more information concerning their composition and production. The combustible fraction of demolition wastes is composed of wood, roofing material, stucco, metal lathe, etc., with an average density of 350-450 pounds per cubic yard. The noncombustible fraction is composed of bricks, masonry, rock, concrete, rubble, etc., and has an average density as high as 1800 pounds per cubic yard. The combustible material produced averages 10 percent, but may exhibit a high variability in specific cases. The composition of the waste, insofar as elemental or pollutant constituents, is unknown. General composition of construction and demolition wastes would seem to indicate the pollutants do not appear to be significant for these wastes. Due to the heterogeneity of the waste, any general analysis relating to pollutants and possible environmental effects would not be meaningful.

Among the major industrial categories, demolition ranks as one of

Table 5

New Construction Waste Debris Production (38)

Type of Structure	Debris Removed cu yd
1-family frame	15
1-family brick	15
2-family frame	20
2-family brick	20
6-family tenement frame	30
6-family tenement brick	30
1-story 100- by 200-ft building	70

the highest in solid waste production with an annual quantity of 21,000 tons per year for disposal (39). Demolition also ranks as one of the highest in solid waste production per employee with an annual quantity of 200 tons per year per employee for disposal as compared to 1.8 tons per capita for municipal refuse production. Typical waste volumes associated with demolition are presented in Table 6.

Methods of collection and transport

Collection of construction and demolition wastes and transport to disposal are usually the responsibility of the contractor. In many instances, specific ordinances make collection of this waste type the responsibility of the contractor and prohibit municipal collection (40). The reason is that a substantial portion of the waste is bulky and may not be collected by conventional methods employed for municipal refuse. Specifically, in the case of demolition wastes the contractor has the available equipment on site for waste processing. Equipment such as bulldozers and front-end loaders is used to collect and load hauling vehicles.

Transportation of construction and demolition wastes is usually accomplished by trucks ranging in size from 5 to 55 cubic yards. Haul distance to the disposal site is a function of waste source location, but usually varies from 10 to 40 miles. Transportation is becoming an increasingly important cost factor for disposal of this waste category where on-site disposal or volume reduction via incineration is prohibited by air pollution regulations.

Productive use and reclamation

The possible dispositions for construction or demolition solid waste include salvage, incineration, and land disposal. There is no potential for land application of construction and demolition wastes for agricultural purposes.

Salvage was used extensively in the past, particularly for demolition wastes with a majority of the waste products being recycled into the economy. Presently, the cost of labor and lack of semiskilled labor has resulted in a nonsalvage type of demolition. The nonsalvage mode utilizes machinery for demolition, and disposition is usually directly

Table 6

Demolition of Typical Structures (38)

Type of Structure	Waste Production Cu Yd	Waste Production Tons
1-family frame (25- by 100-ft lot)	160	56
1-family brick (brick salvaged)	160	56
2-family frame	200	70
2-family brick (brick salvaged)	200	70
6-family tenement frame	800	280
6-family tenement brick (brick salvaged)	800	280
100- by 200-ft commercial or factory structure (1-story brick, light bay, wood trusses, wood roof, concrete floor, miscellaneous pipings, electrical, etc.)	4,200	1,470
1- to 3-story hotel, apartment, commercial complex (approximately 100- by 100-ft, extensive brick, metal, stone salvaging)	4,000	1,400

to a disposal area. A certain amount of salvage is still practiced for specific waste materials where there is a product demand, such as in the case of bricks. For the construction and demolition industry, a lack of recycle seems to be predominantly related to a lack of economic incentives (39).

In the case of combustible wastes from construction and demolition, on-site incineration was practiced previously for a large volume of the waste. In some cases this disposal option is still exercised in specific geographic localities (40), but as mentioned previously, is usually restricted due to air pollution regulations. On-site burial of construction wastes is also practiced when the site area is sufficient to accommodate the waste volumes produced. Incineration of the combustible fraction at central locations or municipal incinerators appears to be a satisfactory disposal alternative. Problem areas associated with this alternative include the heterogeneity of the waste and air pollution control costs associated with municipal refuse incineration (39). These problems will generally continue to impede utilization of this alternative for disposal of construction and demolition wastes.

Land disposal of construction and demolition wastes seems to be the most popular means of ultimate disposal (37,39). Forms of land disposal commonly used include open dumping, landfill for reclamation, or sanitary landfill. The use of open dumping is being restricted due to regulatory efforts. Landfill for reclamation is defined as the use of this waste for filling land areas which are low and for topographic improvement. As defined above, this disposal method generally constitutes a productive use for this material. A good example of this is in Toronto, Canada, where construction and demolition waste has been mixed with dredged material to create an extensive shoreline park system and complex recreational islands (33). One of the parks, Ontario Place, has been extensively developed with theaters, lakes, and other recreational facilities. In most cases the only problem associated with this disposal option is obtaining a uniform grade due to bulky items which may be included in the waste. Since land reclamation accrues a benefit to the disposal area, the costs for disposal are minimized and may result in a profit for the disposal operation. The use of this option is directly related to haul costs associated with this option and its comparison with other disposal alternatives.

The use of sanitary landfill for disposal of construction and demolition is an environmentally acceptable disposal procedure. Sanitary landfills represent a true disposal process which may have ultimate site usages that are productive. While no regulations, per se, exist governing disposal of these waste materials in sanitary landfills, guidelines are available (41,42). These recommended procedures suggest segregated disposal of construction and demolition wastes. The principal reason for this procedure is the heterogeneity of the waste and frequent presence of bulky items. Inclusion of these materials with municipal refuse may result in differential settling of the final site hampering ultimate use for productive purposes. In many cases these wastes may be utilized for road base material within the disposal site, but are generally not suitable for cover material. The disposal of construction and demolition wastes within sanitary landfills is generally acceptable providing sufficient operational safeguards are considered.

Social and psychological concerns

Public attitudes towards the disposal of construction and demolition wastes are principally confined to nuisance conditions, such as dust, which may arise as a result of transport or disposal. The conditions may be controlled by proper operation and do not represent significant problems. Since these wastes are generally not noxious in characteristics, problems which may exist for other solid waste materials are not apparent for construction and demolition wastes.

Future trends

Present indications seem to imply that land disposal of some manner will represent the fate of a majority of construction and demolition wastes. In many cases these materials are very stable; consequently, they may be used as landfill material without subsequent deleterious environmental effects.

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